High-Tech Hazards

Never have technologies developed at a faster rate. Hardly a day passes that doesn't see the introduction of some breakthrough, with rapid advances occurring in such wide-ranging fields as electronics, composite materials, and genetic engineering. And, as has been the case since humans first toyed with fire, with new technologies come risks to human health, some obvious and some difficult to predict.

To cope with these risks, some people have started to think of workplaces as environmental niches in which humans are a natural species and are made vulnerable by the technology around them, says Carroll Pursell, a technology historian at Case Western University. "We're like spotted owls," he says. "We're not sure how these things are going to affect us." Such heightened environmental awareness has developed throughout the twentieth century. "But it's not a steady curve of increased concern. It comes and goes in more-or-less 30-year cycles," Pursell explains. Public and governmental attention to the hazards associated with emerging technologies started with the Progressive movement at the turn of century, flared up again with the New Deal in the 1930s and 1940s, and peaked for a third time with the radical baby boomer movements of the 1960s and 1970s.

These peaks, says William Burgess, a former Harvard professor of industrial hygiene, represent reactions to leaps in technological advances. "Right after the Second World War, in the late 1940s and early 1950s, there was a very dynamic shift in manufacturing technology, but there were also few regulatory boundaries in place," he says. This shift was followed by increases in both governmental and industrial attempts to predict the impacts of burgeoning technologies. But after each period of increased concern, Pursell says, the resulting government institutions have been eroded by backlash from vested interests. The current round of governmental budget slashing represents such a reaction, he says.

In spite of recent governmental downsizing, Burgess says, a century of experience with predicting the impacts of emerging technologies has left a robust regulatory infrastructure and a cadre of environmental health professionals. "My prognosis is that in the '90s and in the future—especially because of EPA and OSHA—we have a better shot at looking at what we're introducing and anticipating problems from it." And, he says, although new technologies often result in health impacts that are difficult to predict, "now, the technologies that are coming in have gone through some review because [manufacturers] have to be sensitive to regulations."

Fibers and Fine Particles

Perhaps no material in the last 20 years has been examined more extensively for health impacts than fibers, both natural and man-made. Much of that attention can be attributed to the risks now known to be associated with asbestos, once considered a miracle material. Asbestosis—a blanket term for lung diseases related to asbestos including mesothelioma (cancer of the peritoneal cavity), lung cancer, and lung fibrosis—first drew serious study in the 1930s, although it had been identified decades earlier. But it was the burst of asbestosis starting in the 1960s—a result of wide-spread wartime use—that led to research that has identified the properties of asbestos that make it, and perhaps similar materials, hazardous.

Often appearing where asbestos would have been used, glass and ceramic fibers are found in such applications as insulators, friction materials (such as automobile brake pads), and structural components. Many of the new fibers share some or all of asbestos's characteristics. Exactly which of these characteristics could spell trouble for people that come into contact with the fibers is still the subject of debate.

Seeking an elusive combination of high strength and light weight has driven engineers to develop a staggering variety of new fibers and particles. Typically composed of various combinations of ceramics, polymers, and metals, these composites can pose a health risk to workers who inhale fibers and particulates, and may present health hazards as serious as those of asbestos. "We're introducing new materials, and it's hard to predict what their toxicology might be," says Vincent Castranova, chief of the Pathology and Physiology Branch of the National Institute for Occupational Safety and Health (NIOSH). "In some situations, they have developed fibers that seem to be less toxic, but in other situations there are fibers that are not necessarily less toxic, and so are not necessarily better," he said.

Predicting the impacts of fibers and dusts can be tricky, Castranova says, because biological effects take a long time to appear. "So we won't have a read on what the occupation hazards might be from the worker population for maybe 20 years or so after the introduction of a new fiber," he explains. Working from animal models, however, researchers have identified many of the characteristics that appear to affect a material's fiber toxicity. "What we've learned from asbestos is that the fiber geometry and the fiber size and its durability are important in health effects," says Brooke Mossman, a University of Vermont cell and molecular biologist. "If you want a . . . safe fiber, you need to make one that is not durable, that will dissolve in lung tissue and not persist and cause disease," she said, although such fibers would probably have limited applications. Most important, she says, is whether the fibers can be inhaled at all. Fibers larger than 10 microns in diameter won't penetrate deep enough into the lungs to cause disease, she says.

Unfortunately, many of the most desirable manmade fibers have many of the least desirable health-related characteristics. High-performance ceramic fibers—which are made from raw materials such as silicon carbide, boron, carbon, zirconia, and alumina—combine the high melting points (greater than 1400°C) and durability needed for such applications as high-temperature insulation, reinforced structural materials, and high-wear components such as bearings, piston rings, and cutting tool inserts. In 1987 the Office of Technology Assessment projected that, although currently limited, these applications would grow to a $1–$5 billion dollar per year business by the turn of the century. Much of this demand would be generated from the automotive industry's drive to decrease the overall weight of vehicles. Many of these materials, however, may also pose serious health risks. Unlike glass fibers, which are usually designed to be soluble in tissue, ceramic fibers are durable, persisting as an irritant in lungs. Like asbestos, ceramic fibers also tend to be very rigid. This rigidity may allow them to penetrate the peritoneal cavity, possibly leading to mesothelioma, Castranova says. Fibers that are long and thin exacerbate these problems. The hypothesis, he says, is that because the lung can't engulf long fibers, its tissues secrete damaging enzymes and reactive oxygen radicals. And even fibers that are soluble enough for lung tissue to absorb may persist in the peritoneal cavity.

Where possible, Castranova says, the fibers industry, which provides much of the funding for fiber toxicity research, tries to avoid combinations of characteristics that result in potentially toxic materials, but "sometimes the constraints of the application don't allow that." Fibers for high-temperature insulations, for example, must be durable to withstand heat and convoluted to trap air. But their twisted shape also helps them to be trapped in the lungs.

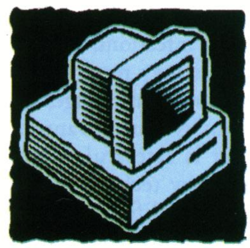
Manufacturers also prefer the least toxic fibers possible, says toxicologist Candice Wheeler, a General Motors staff research scientist. "All materials, before they get into the product or into the process, have to be reviewed for both their health and their environmental impact," she says. "There are several engineering controls you can implement to minimize exposure from the very beginning." For example, GM installs high-powered fans and electrostatic filters, and, when practical, asks that raw materials be delivered as pellets rather than loose fibers. "Our standard so far is that we've been very conservative and we treated almost everything as asbestos," she explains. "That way we know we will protect our workers to the best of our ability."

Although the risks of toxic airborne fibers have been well accepted for several decades, ultrafine articles—those smaller than 0.1 microns—are just beginning to be investigated as a potential health concern. Ceramic powders are finding their way into many types of high-tech composites. For example, particles of such materials as silicon carbide or graphite are added to lightweight metals—typically aluminum or magnesium—to significantly stiffen and strengthen them. Some researchers, however, now suspect that ultrafine particles may cause diseases similar to those of toxic fibers. "There has been a renewed interest or renewed realization that maybe the fine particles are the ones that have an important role that has been overlooked," says George Guthrie, a mineralogist and geochemist at Los Alamos National Laboratories.

Even normally inert materials, such as titanium dioxide, silica, and aluminum dioxide, may become biologically active when broken into very small particles, explains University of Rochester toxicologist Gunter Oberdörster. As particles get smaller, their surface area increases in relation to their mass. Like chemical catalysts, ultrafine particles may be more reactive because of their greater surface area. And, adds Wheeler, smaller particles reach deeper into the lungs.

In fact, she says, researchers don't have a good understanding of the mechanisms that may contribute to the toxicity of ultrafine materials. Studying these materials presents special problems. Epidemiological studies, she says, are inconclusive because the particles are rarely found in pure form outside the laboratory. Instead, they are often contaminated with other materials that have been absorbed onto their surfaces. Animal tests are also inconclusive, according to Robert McCunney, director of environmental medical services at the Massachusetts Institute of Technology (MIT). When exposed to high levels of ultrafine particles, rats develop tumors, but hamsters and mice don't. "This whole business of lung overload in the rat model has thrown a proverbial monkey wrench into the risk assessment [for ultrafine particles]," McCunney says. "Many reputable authorities are of the opinion that the rat model may not be appropriate for predicting human risk when conditions of lung overload occur."

Computer-related Technologies



Since the explosion of workplace computing started in the 1970s, a wide array of physical ailments has been linked to long hours spent staring at cathode ray tubes and pounding on keyboards. In some professions, such as data entry, more than 50% of workers report repetitive stress injuries to their hands or wrists. "Here we have an office technology that has completely changed that particular population," says industrial hygienist William Burgess. Additional physical symptoms that have been reported include back and neck pain, spontaneous abortions, and gastrointestinal ailments, although a cause-and-effect relationship has not always been substantiated.

"There is no one solution for these problems," says Louis DiBerardinis, industrial hygiene officer for MIT. Some repetitive stress injuries, such as carpal tunnel syndrome, may be prevented by using innovative ergonomic keyboards with nontraditional key arrangements that guide the hands into more relaxed positions. Keyboards with audible "clicks" can help workers prevent the fingers from bottoming out at the end of keystokes, which sends damaging vibrations through the hands. And flexible workstations, with adjustable keyboard trays and monitor stands, help people find the perfect computing posture and vary their orientation during the course of a workday. Often, DiBerardinis says, avoiding injury is as simple as taking frequent breaks or learning new typing techniques.

But for some people, none of these approaches seem to work. Recently, the idea has emerged that many of these physical symptoms have their origins in psychological stress. "Up until about five years ago, most of the concentration [was] on the physical aspects of work and how to change, say, workstation design, equipment design, and so on to relieve some of the problems people were having," says NIOSH psychologist Naomi Swanson. "The design of the physical work environment for computer users has rapidly changed and is much better than it used to be, but people still keep having problems, and the problems seem to be increasing." The source of many of these problems, she says, may be workplace stress associated with new computer technologies.

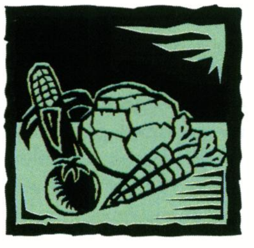
In the short term, stress can lead to depression, tension, and anxiety. Over extended periods it may result in physical ailments such as high blood pressure and migraines, as well as increased vulnerability to physical injuries and infections. Stress-related physical ailments may result from increases in muscle tension and changes in the autonomic nervous system, Swanson says. "For anyone, it is stressful when they're asked to learn new technologies," say Lawrence Rosen, a California State University–Dominguez Hills psychology professor who specializes in the psychosocial effects of computer use. A survey of federal workers, for example, found that 84% felt undertrained on the computers they use, and 80% complained that they didn't have adequate time to learn how to use their computers.

Workplace stress-related ailments can increase dramatically when workers' performance on the computer is remotely monitored. Supervisors for data entry workers, for example, often remotely track the number of keystrokes completed each hour. And telemarketers and reservations clerks are monitored to make sure that the number and average length of calls they handle fall within acceptable limits. Such monitoring methods are counterproductive, says Janet Cuhill, a psychology professor at Rowan College of New Jersey. "The technology should do no harm at the very least and should improve the work environment at the best." In a project to find the best ways to incorporate technologies into the workplace, Cuhill is helping to introduce computers to an agency that deals with child abuse. "When we introduce the computers," she explains, "we don't just say 'this is going to make you work faster or work differently.' We expressly measure what changes occur as a result in the work environment itself." It's important, she says, to provide adequate training, to allow workers to control their own pace, and to have tasks away from the computer. "We also avoid the obvious hazards, which are monitoring keystrokes and . . . breaks, and those kinds of things," she said.

For many people, the revolution in personal computing has not only changed the nature of the workplace, it has changed its location. "The computers allow telecommuting, which allows a reduced level of stress," says Wendall Joyce, a psychologist for the U.S. Office of Personnel Management, who recently completed a review of the federal telecommuting program. Most telecommuters in both government and private sectors report that working at home significantly lowers their stress levels. Anyone who must look at a computer monitor constantly will develop psychosomatic stress and tension, he says. "But in a standard workplace, most don't feel as though they can take breaks because it looks like they're loafing. In their own work environment, they can probably take those breaks and still keep up the productivity without worrying about that."

Yet, others worry about the effects of isolation from the actual workplace and lack of socialization with coworkers on the emotional and ultimately physical well-being of workers. Like women and children who toiled at home on piecework more than a century ago, many workers are now isolated from their fellow workers. Where once the product might have been matchbooks or artificial flowers, now computers allow home-based workers to produce items from completed insurance forms to sophisticated computer programs. Although the potential health effects of the contrasting freedoms and isolation of the home workplace are not well understood, some experts predict that within 10 years some 25% of Americans will work outside of traditional venues.

Transgenics



Genetic engineering, in which genes that code for desirable traits are transplanted from one organism to another, is a rapidly expanding field with applications in research, agriculture, pharmaceuticals, and bioremediation. It is also a battlefield on which prodevelopment industry and academic professionals face off against environmentalists and public health advocates over the safety of transgenic techniques and organisms. People on both sides disagree on the magnitude of the potential risks genetic engineering poses, whether it is the technology of transgenics or genetically engineered organisms themselves that deserve special scrutiny, and whether current federal regulations are adequate to patrol transgenic products.

An example of the debate concerns the risk of introducing allergens to the food supply. Recently, for example, Pioneer Hi-Bred International decided not to market a strain of soybean that was found to trigger a reaction in people who are allergic to Brazil nuts. Normal soybeans lack two of the 20 amino acids that combine to make complete proteins. To round out the set, researchers inserted a Brazil nut gene that encodes for the missing proteins, methionine and cysteine. With the protein, however, came the allergen. "That demonstrated something that those of us in the environmental community had said for years: that sooner or later someone is accidentally going to transfer an allergen into a crop plant with genetic engineering," says biologist and Environmental Defense Fund Senior Scientist Rebecca Goldburg.

Genetic engineering proponents say that they, too, could have predicted that borrowing genetic sequences from common allergenic foods would eventually result in such problems. But, they maintain, the allergen was identified and the company voluntarily withdrew the product. "To me, that says the system worked," argues Peggy Lemaux, a microbiologist at the University of California–Berkeley. Food and Drug Administration regulations require that companies test genetically altered plants if they suspect that the plant will cause allergic reactions. From the FDA's viewpoint, such suspicions are reasonable if the genetic material is borrowed from any of a group of foods—such as crustaceans, milk, eggs, legumes, fish, and nuts—to which many people are allergic.

"That policy is far too narrowly focused," says Goldburg. "There is no scientific distinction between commonly allergenic foods and uncommonly allergenic foods." Under the current policy, she says, people with less common allergies—say, to bananas—will become increasingly at risk as more foods with borrowed sequences enter the marketplace. "The people who will have absolutely no protection are people who may at some time in the future find that they are allergic to a protein from a nonfood source."

If genetically engineered foods are to be sold, Goldburg and other transgenics conservatives say, they should be labeled with the source of the added genes. Additionally, industries should notify the FDA of all new genetically engineered foods they release. That would permit a sort of "food recall" if consumers began reporting new allergies.

Neither of these suggestions pleases pro-transgenics groups. The food industry resists the added expense of such comprehensive labeling, and they may be reluctant to dull consumers' appetites with labels listing genes from nonfood sources such as bacteria, or odd combinations such as flounder genes in tomatoes. And tracking foods just because they were genetically engineered simply doesn't make sense, says Martina McGloughlin, associate director of the biotechnology program at the University of California–Davis. "We've been modifying our food supply since the beginning of time. And although people would like to think when they go into the supermarket that the fruits and vegetables that they see there have been like that forever, even if you look 50 or 100 years ago, the produce was very much different than it is today. That's because human beings have been involved in changing them."

The trick, says Thomas Zinner, a biologist with the University of Wisconsin–Madison's biotechnology center, is to distinguish between the tool itself and the products it produces. "Do you regulate based on what was done or how it was done?" he asks. Each product should be evaluated on its merits rather than on the technology that was used to produce it, he says. "To imply that there are no risks of introducing allergens through selective breeding isn't accurate. There are risks based on your gene pool. What recombinant DNA technology does is expand your gene pool."

But that expansion is the core of the problem, Goldburg says. "If you are, say, breeding soybeans with each other, the chances are that all of the soybeans that you are crossing contain the same suite of allergens. Transgenic plants can contain genes, at least in theory, from any other organism. There's a whole new spectrum of proteins we can put into the food supply. I would argue the odds of putting an allergen into an unexpected place are much higher with genetic engineering."

Just as intense as the debate over direct human health impacts from transgenics has been the disagreement over the indirect impacts through potential environmental damage. One such area includes plants that have been engineered to carry the genes for natural insecticides. Monsanto, for example, is in the process of adding the bacterium *Bacillus thuringiensis*, or Bt, to potatoes. As unappetizing as it may sound, there are no apparent risks from eating such plants. The insecticidal proteins are not toxic until they are broken down into toxins in the insects' highly alkaline stomachs. And humans don't have receptors for the insect-specific toxins. But, some environmentalists argue, engineering bacterial insecticides into plants could drive insects to evolve resistance to the common, environmentally benign insecticide.

"When you starting putting Bt into crops like corn and planting them on a large scale, so that the Bt is present in the plant all the time, insects will be affected by it every time they feed on the plant and the selection pressure for Bt resistance is going to skyrocket," Goldburg says. "There is virtual unanimity among the entomology community that if we put Bt out on the market without any plan for managing the evolution of resistance, we can kiss it goodbye." Such a situation would leave organic farmers, who depend on Bt, without one of their only acceptable insecticides.

The answer, McGloughlin says, is to both closely regulate the application of Bt-containing plants and to develop many versions of the plants, each with a different strain of the insecticide. Like any new technology, people have to adjust to its strengths and weaknesses. "Biotechnology is a tool and people will use the tools that are available to them," she says. "Gradually there will be greater and greater use of this tool as people get used to it."

We are in the midst of a second industrial revolution, says Tai Chan, program manager of occupational health and safety research for General Motors, one in which new high-tech materials are entering the workplace at an almost overwhelming rate, and the nature of the workplace itself is steadily changing. Although some new technologies may present new hazards, Chan says, as researchers are better able to predict environmental and health hazards, they will develop other new technologies to mitigate such risks. "Technology should be about the exercise of prudence," says Pursell. "But economic considerations usually push new developments forward."

Scott Fields